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Summary

Equipment has been constructed in which the bit-rate of a digital video signal is reduced by removing the line-blanking portion of the video waveform. This enables the digital video word rate to be reduced from three-times colour-subcarrier frequency, $3f_{sc}$, (13·300875 MHz) to 704-times television line frequency (11·000000 MHz).

Associated signal-reconstituting equipment has also been developed to re-generate the line-blanking portion of the waveform and restore the digital video word rate to $3f_{sc}$; this equipment was specifically designed for use in digital video recording experiments; the output signal being synchronised with an external reference colour-subcarrier signal.

Issued under the authority of

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1. Introduction

In digital video recording experiments using longitudinal tracks on 25·4 mm (1") magnetic tape moving at 120 i.p.s. it has so far been found difficult to achieve a sufficiently high packing density to be able to record 8 bit p.c.m. samples at a rate of three times subcarrier frequency[1] (13·300875 MHz).

Removing the line-blanking portions of the digital video signal and re-distributing the remaining samples is one way in which the sample rate can be reduced for recording. Moreover, if the information normally included during the line-blanking interval is accurately conveyed with the re-distribution video signal, albeit using a relatively small number of control-data words, this technique for bit-rate reduction need not introduce any visible impairment of the reconstituted video signal.

Although the principle of removing the line-blanking portion of the digital television signal could equally well be applied in the transmission of digital video signals, the equipment, particularly that for reconstituting the signal, and the choice of transmission parameters would probably be different.

The equipment is designed* to accept an eight-bit, linearly coded video signal whose sample rate is three times colour subcarrier frequency ($3f_{sc}$), phase-locked such that every third sample is phase coincident with the +U (unswitched) axis of the composite PAL video signal. It is also assumed that the coded signal has been clamped such that the black level is coded as p.c.m. code value 64 (where full scale is $2^8 - 1 = 255$).

The signal reconstituting equipment contains a buffer store which is designed to combine the functions of redistributing the sample values, restoring the sample rate to $3f_{sc}$, regenerating sync pulses, and removing any timing jitter which may have been introduced. The final output is synchronised to the local reference subcarrier, pulses being generated to control the average speed at which samples are replayed. By these and other means the design of the apparatus was simplified but, it is thought, a performance has been retained which is adequate for the applications envisaged.

* A large part of this apparatus was designed by C.D. Mathers.

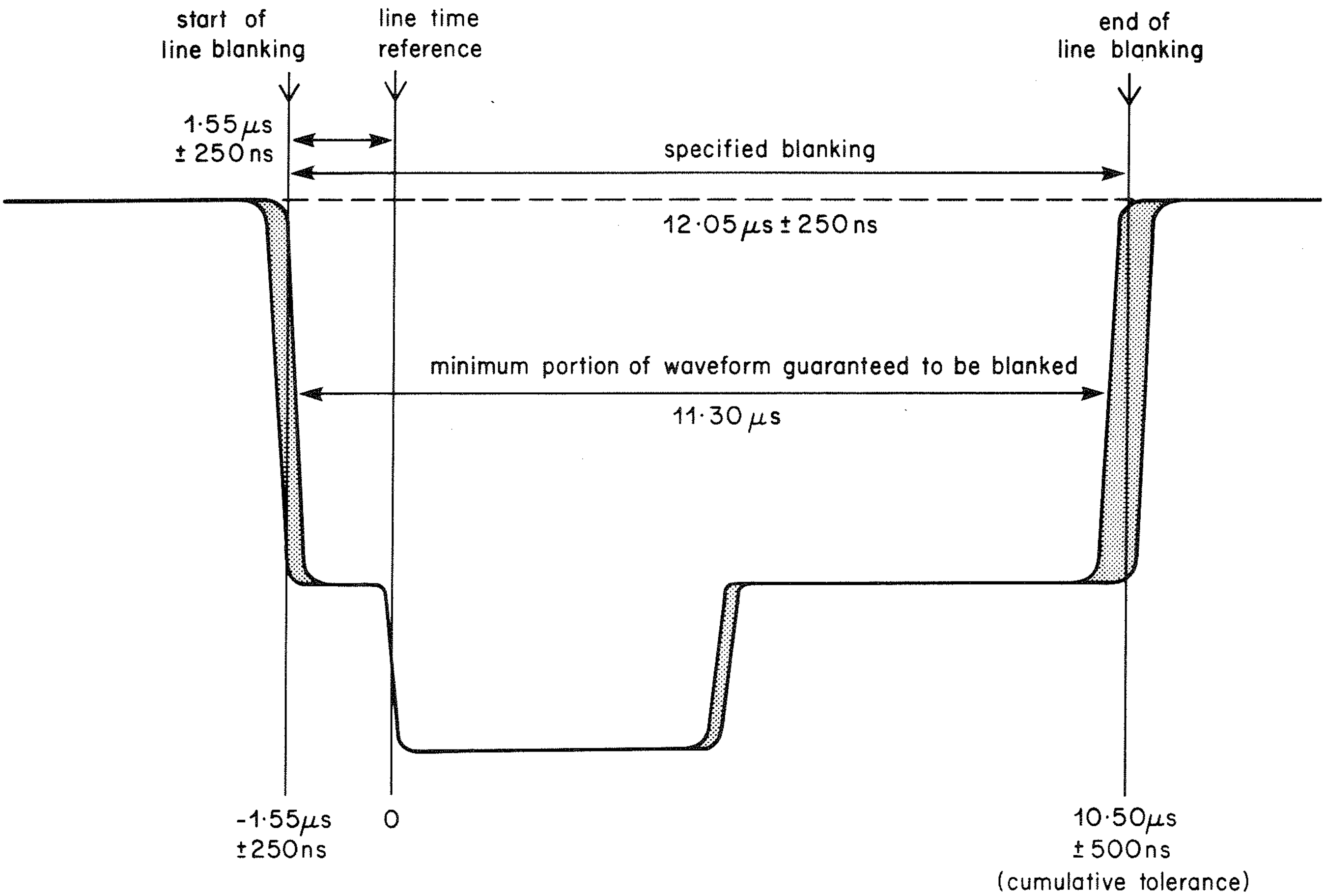

Fig. 1 - White Book specification of line-blanking

2. The line-blanking interval

Fig. 1 shows the line-blanking interval as specified in the 'White Book', for 625-line System I PAL signals.[2] It effectively states that the minimum duration of the line blanking interval is 11·30 μs. In present BBC practice, however, it has been found that a more realistic minimum value would be nearer 11·50 μs.

With an initial video sample rate of $3f_{sc}$, some 153 samples could be omitted from the 851 (or so) samples describing each video line. Thus, the active portion of the line can be transmitted using 698 samples. For the present application it was decided to use 699 samples per line, allowing a one-sample tolerance for locking to the line-time reference. It was chosen to use an equal number of samples for each line so as to simplify the design of the apparatus for the applications where only a part of each television line is of interest.

3. Coding the information normally conveyed by the television waveform during the line-blanking interval

As discussed earlier (in Section 1), the apparatus was designed to accept a $3f_{sc}$ sampled video signal where the sampling phase is locked to a particular phase of the colour subcarrier. Further, it was decided that the reconstituting equipment should re-insert a standard level sync and burst waveform in the output digital video signal. With these constraints, it is necessary to transmit the following line and colour-burst blanking information in codes, time-division multiplexed with the digital video signal so as to enable the composite television waveform to be reconstituted:

(i) the timing relationship between the line-timing reference (the leading edge of a line-sync pulse) of the original signal and a reference sample S_{ref} of the digital video signal, expressed as a proportion of a sample interval.

(ii) identification of the phase of S_{ref} relative to colour subcarrier (one of three phases).

(iii) the sense of the V-axis switch.

(iv) television line-number identification.

(v) identification codes to enable the blanking-information code-words to be separated from the digital video signal.

Methods of generating line-locked pulses from subcarrier-locked clocks have already been described in connection with digital television waveform generation.[3] It has been established that a counter can be programmed to give the sample which is closest to the line-timing reference for each line of a television waveform; the program is based on the mathematical relationship between colour subcarrier frequency and television line rate. Moreover, such a procedure can be extended to give a 'residue' that is a numerical representation of the time between that sample and the line-timing reference as a proportion of a sampling interval.

A counter configuration suitable for $3f_{sc}$ sample rates is given in Fig. 2, and a derivation of the count sequence is included in the Appendix. The four bit 'residue' signal gives a resolution of one sixteenth part of a clock pulse which, with $3f_{sc}$ sampled 8 bit p.c.m. coded video signals, has been found in earlier work[4] to be adequate for System I television. The first part of the counter (add 48 modulo 625) has a cycle length of 625 and can be started at a particular line on the television picture. Thus, it can also be used to assign a re-ordered line number (between 0 and 624) to each line of the picture. The phases of the residue and line-interval counters can be adjusted to optimise the representation of the timing of the line-timing reference. To enable a similar sequence, in the reconstituting equipment, to be phased to regenerate the line-timing reference accurately, the contents of the re-ordered line number counter (10 bits) and the residue counter (4 bits) can be used as control information. The re-ordered line numbers can also be used for television line number identification.

To indicate the sense of the V-axis requires one bit, and the phase of S_{ref} relative to colour subcarrier needs two bits. To enable the information codes to be separated from the digital video stream about two sample words (16 bits) must be allocated for identification codes. These are selected to be data words unlikely to be generated within the normal digital video signal.

Hence, the information normally conveyed by the television waveform during the line-blanking interval can be conveyed as shown below:

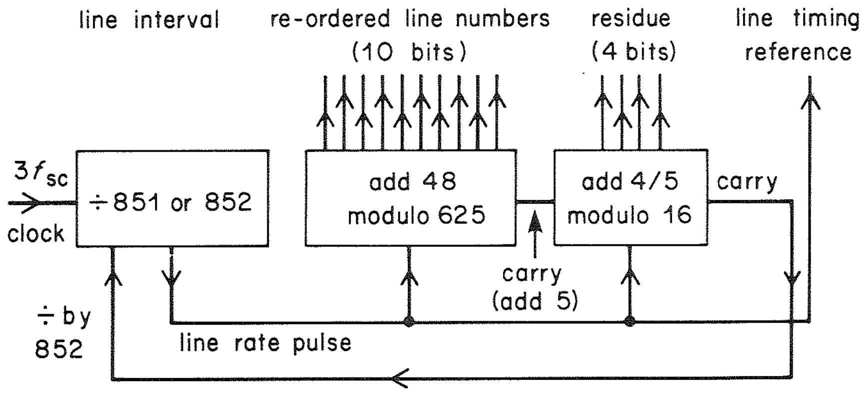

Fig. 2 - Counter configuration to divide from $3f_{sc}$ to line-rate

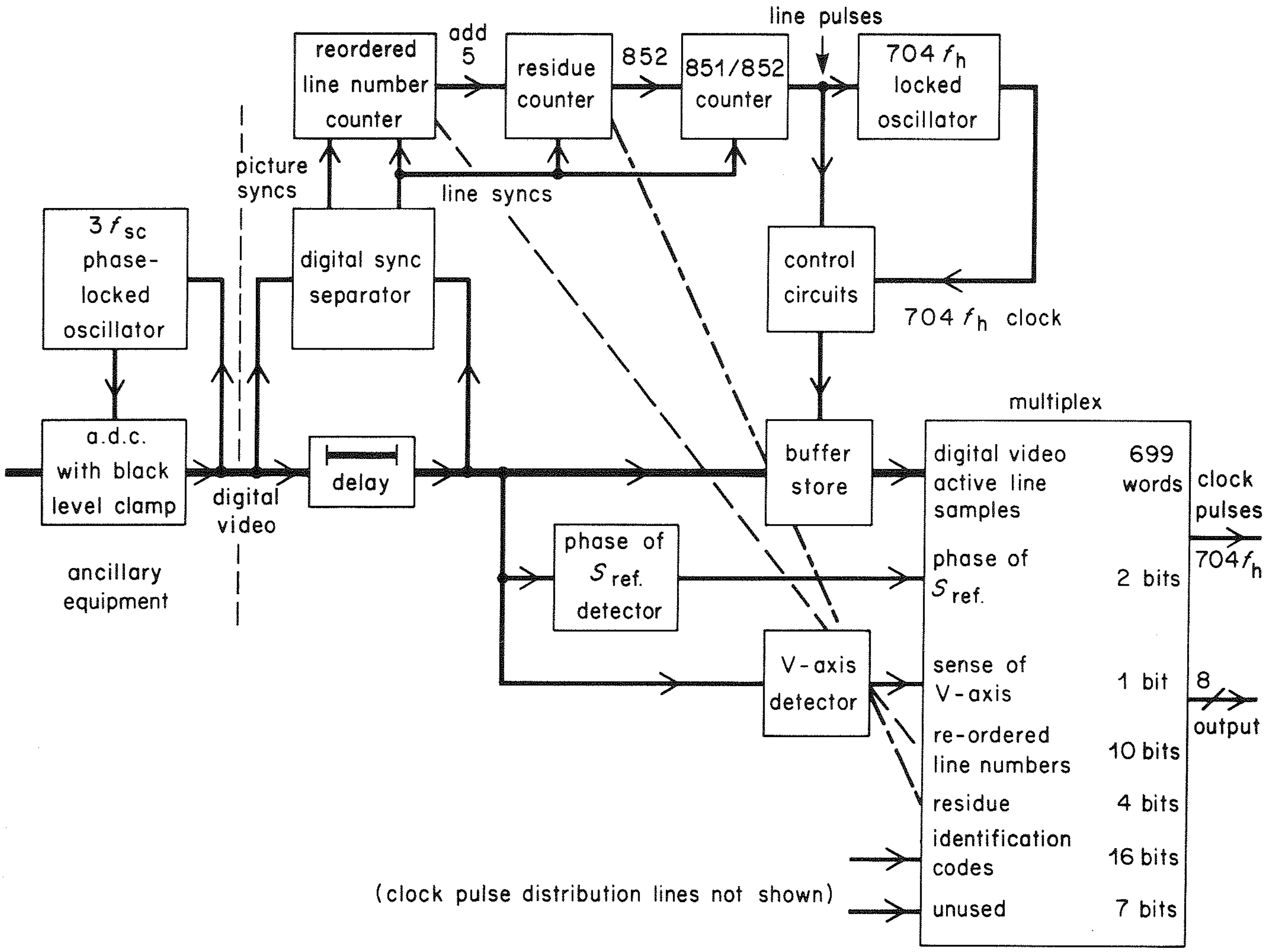

Fig. 3 - Line-blanking remover and signal redistribution equipment — clock-pulse distribution-lines not shown

Re-ordered line number	10 bits
Residue	4 bits
Phase of S_{ref}	2 bits
Sense of V-axis	1 bit
Identification codes	16 bits
TOTAL	33 bits

If these signals are included with each line they are sufficiently redundant not to require further protection against errors. Given one successful reception of each code, others of the same set are entirely predictable as long as the mathematical relationship between colour subcarrier rate, line rate and field rate holds for the signal being processed.

In the present equipment, five, eight-bit words are allocated to convey this information, giving seven unused bits which are available for other purposes. The total multiplexed data stream comprises the 699 video sample words and the five information code words giving a total of 704 words transmitted during each television line period. Thus the total word rate is 704 x f_h = 11·000000 MHz, where f_h = 15·625 kHz, the line-scanning frequency.

4. The line-blanking remover and signal redistribution equipment

4.1. General description

A general schematic diagram is given in Fig. 3 showing the system which removes the line-blanking portion of the digital video waveform, and redistributes the remainder in time. It also generates control information and multiplexes the information codes together with the digital-video sample words to form a single composite data-stream of eight-bit words at a rate of 704 times television line rate.

Retiming the $3f_{sc}$ video samples from the active line portion of the television waveform to have a rate of 704 times line rate is done using a buffer store comprising two, eight-bit parallel shift-registers, the capacity of each being 776 eight-bit samples. Logic gates control the input, output and clock connections to each register and are activated by control circuits such that data are read into one register at $3f_{sc}$ rate while data are being read out of the other at 704 times line rate.

The control circuits are driven by signals from other circuits within the control loop. This includes a digital

sync separator, which will be described below, a crystal oscillator locked to 704 times line rate, a re-ordered line number counter, residue counter and 851/852 line interval counter, whose functions were described in Section 3.

Means were provided to lock the phase of the line interval counter to give optimum representation of the line-timing reference within a tolerance of one $3f_{sc}$ clock period (75 ns). Although means could have been devised to also optimise the phase of the residue counter and hence reduce this tolerance to $\frac{1}{16}$ of this value, such circuits were not included. For the present application the wider tolerance was considered adequate.

The delay, shown in the main signal path, is part of the digital sync separator, but it is installed there so that the digital video signal is correctly timed with respect to the separated sync signals.

Circuits which detect the phase of S_{ref} relative to subcarrier and the sense of the V-axis switch are described below.

The output signal is formed by multiplexing together the re-timed digital video samples and the control information codes.

4.2. The digital sync separator

The digital sync separation design used was an implementation, in the digital domain, of a well-known analogue method. The principle used was that of comparing the video signal with a level midway between blanking level and the bottom of syncs.

An advantage is gained in the digital implementation of this circuit in that the mean values of blanking and sync levels can be accurately established and stored. Further the video signal can then be delayed such that each sync edge can be compared with levels derived from the signal immediately before and after that edge.

In the present apparatus, the timing control for the averaging processes is derived from a simple sync separation where the video signal is compared to code-value 32, half that of black level.

At the output of the sync separator, a series of counters is used to separate the line syncs from the mixed syncs and identify the first line of each picture. These signals are used to control the re-ordered line-number counter, the residue counter and the 851/852 counter.

4.3. Detecting the phase of S_{ref} relative to subcarrier and the sense of the V-axis

In the apparatus, both the phase of S_{ref} relative to subcarrier (one of three possible phases) and the sense of the V-axis switch are determined by examining the relationships between successive sample values during the chrominance burst.

As stated in Section 1, circuits external to the apparatus maintain the phase of the $3f_{sc}$ samples such that one of the three samples describing each colour subcarrier

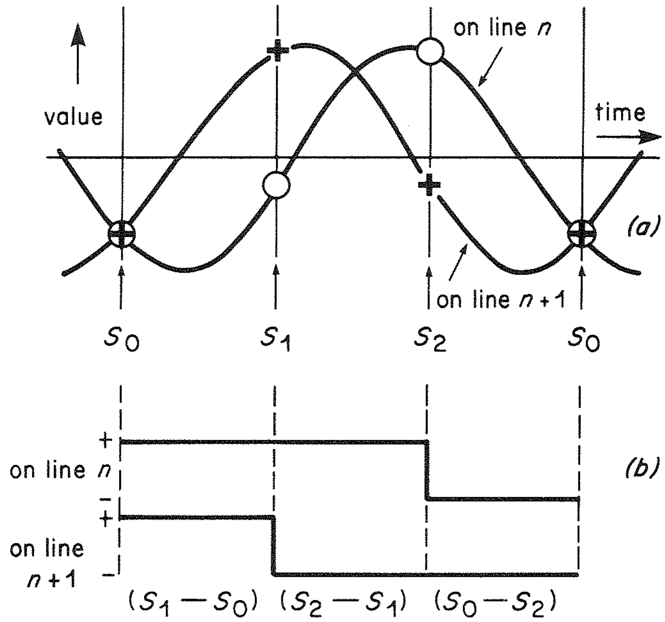

Fig. 4 - Relationships between samples during the chrominance burst
(a) Sample values during the burst
(b) Signs of differences between successive samples

cycle is phase coincident with the +U axis of the colour modulation. Fig. 4(a) shows the sample values resulting from sampling the central portions of the two different colour bursts on successive lines. The three different sample values, relative to colour subcarrier are S_0, S_1 and S_2 where S_0 is coincident with the +U axis of modulation.

Fig. 4(b) shows the signs (+ or –) of the results of the differences between successive samples. By examining this sequence for one colour burst, both S_0 and the sense of the V-axis switch can be identified.

Circuits in the apparatus accumulate the three difference signals in three separate counters so that they are averaged over eight subcarrier cycles in the centre of the colour burst. The averages of the difference signals are then examined to identify S_0 by considering the three as part of a cyclic sequence and locating the transition from negative to positive as shown on Fig. 4(b). The sense of the V-axis is identified from whether one or two of the average difference signals are positive.

To reduce the possibility of spurious operations of the S_0 and V-axis switch circuits by noise, their outputs are applied to flywheels. For the S_0 detector, one divide-by-three counter, clocked at $3f_{sc}$, is started at S_0 on one line and used to check the self-consistency between measurements made on consecutive lines. When consecutive measurements are found consistent, the phase of a further divide-by-three counter, also clocked at $3f_{sc}$, is set. For the V-axis switching signal, a bistable, triggered at line rate, is used as the flywheel. The phase of the bistable is only changed when the measurements of the V-axis switch made on eight consecutive television lines all indicate the bistable to be in the wrong phase.

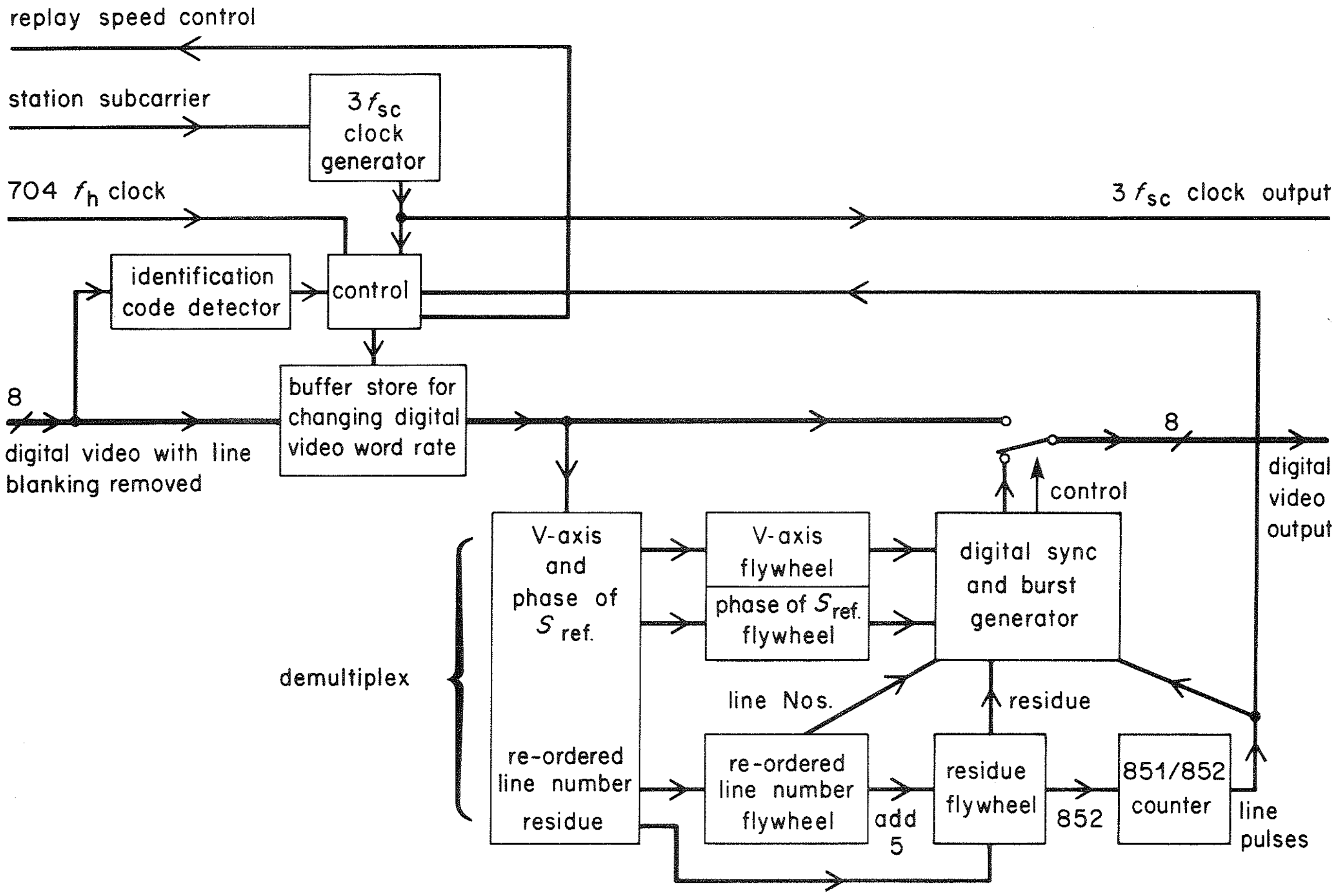

Fig. 5 - Signal-reconstituting equipment — clock-pulse distribution-lines not shown

5. The signal-reconstituting equipment

5.1. General description

A schematic diagram of the signal-reconstituting equipment is shown in Fig. 5. This part of the apparatus includes circuits which detect the identification codes and control the writing of data into a buffer store. The identification-code detector includes a flywheel such that storage of the data can still continue if an identification code is corrupted with errors. The buffer store, as explained in Section 1, is used to redistribute the sample values so as to restore the sample rate of $3f_{sc}$. It is also used to synchronise the output signal with the local station subcarrier, removing any timing-jitter that might have been introduced in the record/replaying process. Circuits are also included to regenerate and re-insert code sequences representing the video waveform during the line and field-blanking intervals.

The buffer store comprises four, eight-bit parallel shift-register circuits each with a capacity of 799 sample words. The input signal is directed to each register in turn by a switch which is advanced to the next register each time an identification code is detected by associated circuits. Signals are clocked out of the registers in turn at a $3f_{sc}$ rate, the four-line capacity of the buffer store enabling a timing variation of ±1 television line for the removal of timing jitter from the replayed video signal. The circuits which control the input and output selector switches for the buffer store also monitor the time for which each digital video line is stored, and generate signals which can be used to control the replay speed of a recorder so that the store is maintained approximately half-full.

At the output from the store, the control information codes are de-multiplexed and applied to flywheels to reduce the effects of any errors that might have been introduced into the digital stream. Signals giving the phase of S_{ref} and V-axis switch are applied to flywheels similar to those employed in the line-blanking remover and signal redistribution equipment.

In the flywheel circuit for the re-ordered line numbers, each new number is checked for consistency with the previous number. The action of this circuit is depicted in the flow diagram in Fig. 6 where R_1, R_2 and R_3 are the contents of temporary storage registers and F is an operator which converts one re-ordered line-number to the next of the series (using an 'add 48, modulo 625' circuit as in the line-blanking remover circuit). If errors occur, or there is a discontinuity in the received signals, a reserve set of numbers is generated, based on the last correct number received. The flywheel for residue numbers is similar in operation to that for the re-ordered line-numbers.

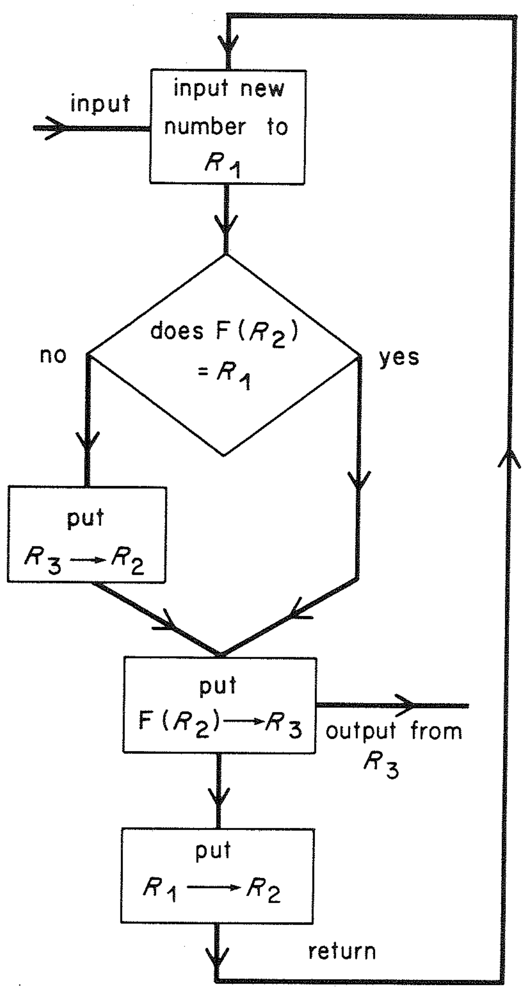

Fig. 6 - Flow diagram for re-ordered line-number flywheel
Note: $R_j \rightarrow R_k$ *denotes 'shift contents of register* R_j *to register* R_k*'*

Signals from the various flywheel circuits control an 851/852 counter and the buffer-store control circuits. They also control circuits which generate, digitally, a mixed syncs and burst waveform and re-insert this in the digital video signal. These waveform generator circuits are described in Section 5.2 below.

5.2. Circuits to generate digitally a mixed syncs and burst waveform*

5.2.1. General

In the waveform generator, the line-timing reference point is re-established for each television line. Then, components of the mixed-sync and burst-envelope, which occur at fixed times during a line period, are generated a discrete number of clock pulses after the line-timing reference. The bursts are formed by multiplying together the burst-envelope signals and a repeated triplet of digital numbers representing samples of a sine wave at colour subcarrier frequency (see below in Section 5.2.4).

5.2.2. Regeneration of the line-timing reference

The line-timing reference signal is regenerated as a set of digital sample values describing a negative-going linear ramp from black level to sync bottom.

With such a set of sample values, a line-timing reference signal can be generated, such that its half-amplitude point occurs between two discrete sample instants. This process is illustrated in Fig. 7. From this Figure it can be seen that the position of the line-timing reference can be varied by adding a fixed number of quantum steps (N) to each of the sample values describing the ramp. Moreover, if the slope of the ramp is M quantum steps per sampling interval, by simple geometry the proportion of the sampling interval T that the line-timing reference is delayed by is given by the ratio N/M.

In the present apparatus, it was found particularly convenient to choose a slope (M) of 16 quantum steps per sample interval. Thus the ramp can be generated by

* Circuits to generate the digital mixed syncs and colour burst waveform used in this apparatus were designed and constructed by N.D. Wells.

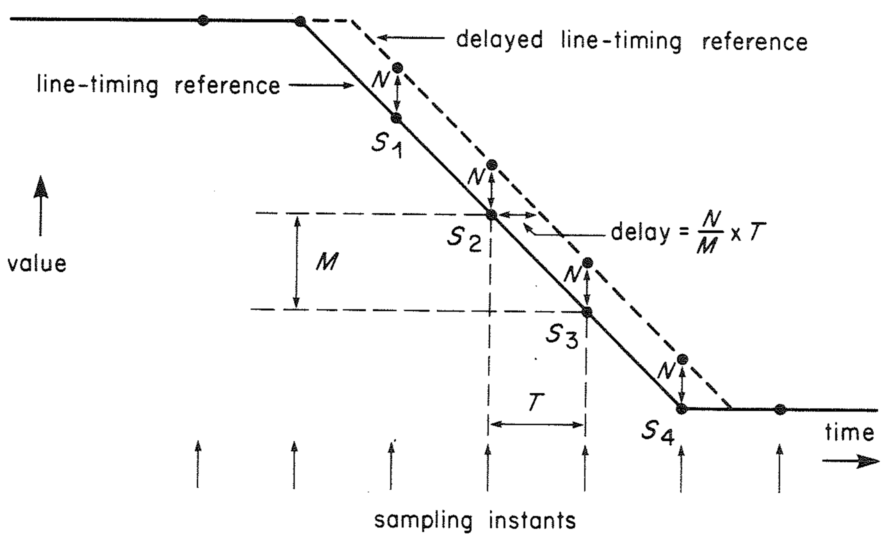

Fig. 7 - Generation of delayed line-timing reference

adding, to a reference set of sample values, the four-bit residue values (B_1 B_2 B_3 B_4) which describe the position of the line-timing reference in 1/16ths of a sampling interval (as described in Section 3). The four eight-bit sample words describing the ramp are then as given below with the most significant digit first.

$$S_1 = 0\,0\,1\,1\,B_1\,B_2\,B_3\,B_4$$

$$S_2 = 0\,0\,1\,0\,B_1\,B_2\,B_3\,B_4$$

$$S_3 = 0\,0\,0\,1\,B_1\,B_2\,B_3\,B_4$$

$$S_4 = 0\,0\,0\,0\,B_1\,B_2\,B_3\,B_4$$

The ramp, as generated above, has a slope very nearly equal to that of a correctly shaped line-sync edge. In the waveform generator, the ramp is properly shaped by applying it to a simple digital transversal filter whose coefficients are +¼, +½, +¼. This rounds the corners of the ramp to give an edge with a 10% to 90% rise-time of 270 ns which is well within the White Book specification[2] of 250 ns ± 50. Fig. 8 compares the shape of a sync edge generated in this way with that of an ideal raised cosine shaped edge with a 250 ns rise-time.

5.2.3. Generation of other edges at fixed positions within a television line

In the waveform generator, the circuits that are used to generate the line-timing reference are also used to generate other edges of the mixed sync waveform and the envelope of the colour burst. For simplicity, all these edges are generated a discrete number of clock pulses after the line-timing reference. Thus, the same residue number is used in generating all edges for a particular television line. As a result, some edges are displaced by up to 35 ns (half a clock period) from their mean specified positions relative to the line-timing reference. This displacement is small compared to the tolerances for the relative timing of edges and is not dependent on the line on which the particular edge is generated.

The generation of a rising edge differs from that for a falling edge in that the residue must be subtracted from the reference set of numbers to displace the edge in the correct direction. This is done, in the apparatus, by complementing the residue number and adding it to a reference set displaced by one sample interval.

The numbers of sample intervals between edges are stored in a programmable read only memory (PROM), which is used to control a programmable counter. The many different intervals between edges are achieved by cycling addresses applied to the PROM once each television line for the line sync and burst envelope, and twice each television line for the field block.

At the output of the edge generator, the mixed sync part of the waveform and the burst envelope part of the waveform are separated. The burst envelope waveform is applied to the colour-burst generator which is described below.

5.2.4. Colour-burst generation

Colour bursts are formed by multiplying together the burst envelope and a repeated triplet of digital numbers describing a correctly phased sine wave at one third of the sample rate.

Referring back to Fig. 4, the precise sample numbers for generating the sine wave (S_0, S_1 and S_2) can be calculated for a colour burst whose peak-to-peak magnitude is 64 quantum levels. On line n these are −22·6, −8·3 and +30·9. On line n + 1 these are −22·6, +30·9 and −8·3.

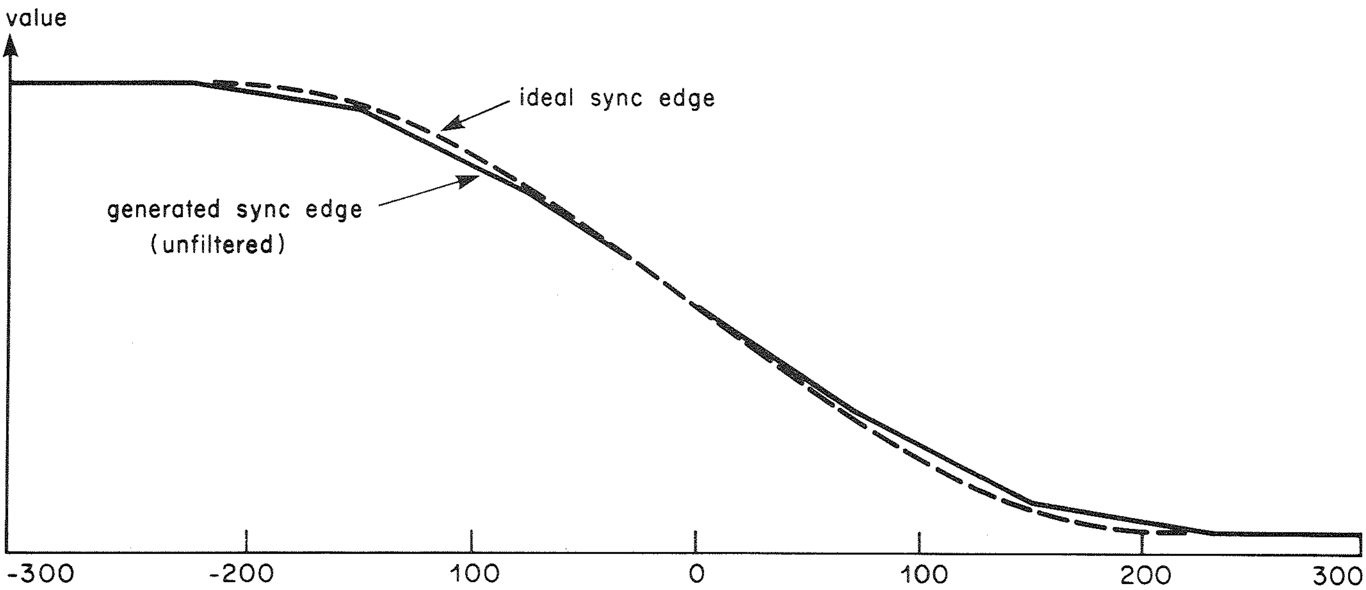

Fig. 8 - Comparison between generated and ideal sync-edges

To simplify the present apparatus these numbers were rounded to −24, −8 and +32. This gives a 1° phase error for each burst, which is larger than the 0·6° error that would have resulted if each number had been rounded to the nearest quantum level. It also gives a burst which is 4% larger than that specified. These errors are outside the White Book[2] specified tolerances of ±½° phase and ±3% amplitude for a signal source. However, these errors are considered acceptable in apparatus for research purposes whereas they would not be acceptable for apparatus intended for broadcast operations where such apparatus would be fitted with a more complex digital burst generator. Thus the output would be more closely in agreement with the broadcast signal specification.

Signals to provide the colour-burst blanking (Bruch blanking) are generated from the line number and V-axis switch information, and are used to set to zero the output from the burst generator.

At the output of the colour-burst generator the colour bursts are added to the mixed sync output of the edge generator. The composite sync and burst waveform is then gated into the re-timed video signal.

6. Construction

The apparatus described was constructed using mainly TTL digital integrated circuits with a large proportion of Shottky circuits. The storage elements used in the buffer stores are 256-bit by 4-bit M.O.S. serial shift-registers. Six of these integrated circuits are mounted on a board (designed in Research Department for storing one digital television line) together with multiplexing, clock drive and control circuits. Three of these boards* are used in the line-blanking remover and signal-redistribution equipment and four are used in the signal reconstituting equipment. Apart from the line-stores, the line-blanking remover and signal redistribution equipment comprises 161 digital integrated circuits mounted on 5 boards and the signal reconstituting equipment comprises 169 integrated circuits also mounted on 5 boards.

7. Performance

The performance of the apparatus has been found to be as required. The input and final decoded output waveforms are shown in Fig. 9. This figure also shows the decoded intermediate waveform with the line-blanking portion removed and the picture signal retimed. Important limitations on the use of the apparatus arise because fixed levels of sync and burst are re-inserted into the reconstituted television signal. Therefore, the input signal must be applied to the p.c.m. encoder with normal standard levels of sync-pulse and colour burst so that the reconstituted output signal has the correct relationships between picture level, sync level, colour burst and colour content of the picture.

* The boards used in the apparatus are of the 4U size in the BBC Binary Metric Module system.

(a)

(b)

(c)

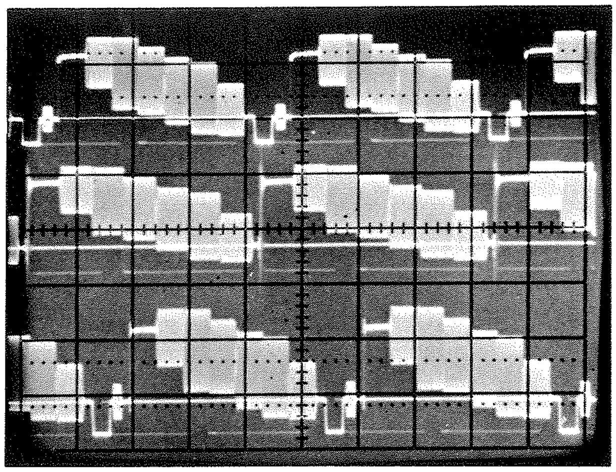

Fig. 9 - Waveforms of the line-blanking remover and re-inserter

(*a*) Input (*b*) Intermediate (*c*) Output

8. Conclusions

Apparatus has been constructed which reduces the bit-rate of a $3f_{sc}$ sampled digital television signal. This reduction is achieved by removing the line-blanking portion from the signal but including with it sufficient data to enable that portion to be regenerated. In this way the sample-rate is reduced from 13·300875 MHz to 11·000000 MHz, a saving of 17·3%.

Although the use of the apparatus is subject to certain limitations, it is suitable for application in digital television recording systems.

The system described has potential for applications to broadcasting systems. For such applications, the positional error of the re-inserted syncs and the phase and amplitude errors of the re-inserted colour burst would have to be reduced. The sync positional error might introduce cumulative displacements of the syncs in successive similar processes applied to the television waveform. However, the maximum value of each such displacement could be reduced from 75 ns to 1/16 of this value by adding more complex circuits to lock the phase of the counters in the line-blanking remover. By fitting a more complex digital burst regeneration circuit in the re-inserting equipment, any phase and amplitude errors in the re-inserted colour burst could be reduced to the order of those normally introduced when a colour signal is digitised using $3f_{sc}$ sample rate and eight bits per sample.

9. References

1. BELLIS, F.A. An experimental digital television recorder. BBC Research Department Report No. 1976/7.

2. Specification of television signal for 625-line System-I transmission. January 1971. BBC and ITA.

3. CHAMBERS, J.P. The use of digital techniques in television waveform generation, IBC 74, IEE Conference publication 119, p. 40.

4. RATLIFF, P.A. The generation of video synchronising pulses and test waveforms by digital synthesis: timing errors caused by quantising distortion. BBC Research Department Report No. 1974/17.

10. Appendix

Derivation of counter configuration to divide from $3f_{sc}$ to television line-rate

The relationship between television line-rate (f_h) and colour subcarrier frequency is defined[2] as:

$$f_h = \frac{4f_{sc}}{1135 + \frac{4}{625}}$$

So the number (n) of $3f_{sc}$ clock pulses in a television line period is

$$n = \frac{3\left(1135 + \frac{4}{625}\right)}{4}$$

$$= 851\tfrac{1}{4} + (3/625)$$

To give a resolution of 1/16th clock pulse for the fractional portions of a clock pulse, this can be expressed as

$$n = 851 + \left[\left(4 + \frac{48}{625}\right) \cdot \frac{1}{16}\right]$$

The latter part of this expression can be simulated using a divide by 16 (4 bit) counter which is normally advanced by 4 counts each line and is advanced by one extra count (i.e. 5), 48 times each picture. The carry output of an 'add 48, modulo 625' counter can be used to give an output 48 times each picture. In a similar way, the carry output from the divide by 16 counter can be used to change the division ratio of the main counter from 851 to 852.

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